Recent Developments in the Process of Manufacturing Lead-Covered Telephone Cable [1]

By C. D. HART

THE manufacture of telephone cable consists essentially of insulating copper wire with paper, twisting two insulated wires together to form a pair, again twisting to form a quad if quadded cable is to be made, stranding these pairs or quads into a compact core, removing moisture, covering the core with a continuous sheath of lead or lead alloy, testing the completed cable and packing it for shipment.

In order to bring out clearly some of the recent developments in manufacturing processes it is necessary to review the beginning of the art.

The idea of using cables for telephonic communication goes back to about 1878. In a talk given in London by Dr. Alexander Graham Bell he stated "It is conceivable that cables of telephone wires could be laid underground, or suspended overhead, communicating by branch wires with private dwellings, country houses, shops, manufactories, etc., uniting them all through the main cable with a central office where the wires could be connected as desired, establishing direct communication between any two places in the city."

About two years later, or in 1880, the idea became a fact and wires enclosed in sheath were used across the Brooklyn Bridge.

The insulation used on these early cables was gutta-percha or rubber but these materials were not very satisfactory for land telephone cables. A little later sisal and cotton were used and the cable core was impregnated to prevent the entrance of moisture and then drawn into successive lengths of lead pipe previously extruded and laid out in straight pieces, the different lengths being then joined together by means of plumber's joints. Impregnation was resorted to because it was difficult to obtain a lead sheath which was entirely free from defects.

By about 1890 paper ribbon had been introduced as a substitute for cotton and similar insulations, effecting, of course, a great saving in space and therefore in sheathing material and cost.

Fig. 1 shows a group of insulating machines used about 1892. With these machines paper ribbon was wound from a spool mounted eccentrically with the wire and the insulating speed was necessarily very slow.

[1] Presented at the Regional Meeting of District No. 5 of the A. I. E. E., Chicago, Ill., Nov. 28–30, 1927.

Fig. 2 shows the twisting machines used at that time for twisting pairs. These machines were crude and operated at a low speed.

Fig. 1—Old insulating department about 1892

Fig. 2—Old twisting department about 1890

Fig. 3 is of an old stranding machine consisting of one drum only as the cable cores were built up one layer at a time and the core was run

through the stranding machine as many times as there were layers in the finished core.

The old process of pulling cable core into lead pipe is illustrated in Fig. 4. This picture was posed a few years ago, and the man standing in the foreground was one of a gang who formerly did this work.

Fig. 3—Old stranding department about 1890

A forward step in design of insulating equipment was made with the use of pads concentric with the wire which permitted very much higher insulating speeds and very much reduced paper breakage. The twisting machines were also modified to reduce uneven twisting and permit greater speed.

Another step was the development of multiple drum stranders permitting a number of layers or complete small cables to be made in one operation. Also, extrusion presses were improved so that a continuous sheath of lead alloy could be extruded directly on to the cable core, eliminating the pulling-in operation.

During the period from about 1900 to 1920 many changes were made to increase output and improve the quality. Improvements in machines made possible the use of thinner and narrower insulating papers so that a greater number of pairs of wires could be placed within the same cross-sectional area, tending greatly to decrease the cost per circuit. Cables made about 1888 contained 50 pairs of 18-gauge conductor. By about 1902 improvements had been made which permitted 606 pairs of 22-gauge wire to be put into a sheath of 2⅜ in.

inside diameter which is the maximum size of sheath which has been found generally economical in telephone plants in this country. By 1912 further improvements in manufacturing equipment made it possible to use insulating paper of even smaller dimensions and to get 909 pairs of wire into the same diameter of sheath.

Fig. 4—Pulling core into lead pipe, method used prior to 1894

On account of increased congestion in the densely populated sections of the larger cities, there was continued demand for more pairs of wire per cable, and in 1914 the first 1,212-pair 24 A.W. gauge cables were produced. This 24-gauge wire was insulated with paper 5/16 in. wide and 2½ mils thick. The mutual capacitance between the two wires of a pair in this cable averages about .079 microfarad per mile, which allows a normal margin below the guaranteed value shown in Table 1.

TABLE 1

A.W.G.	Standard Sizes—Pairs	Average A. C. Capacitance Guarantee m.f. per Mile	Principal Uses
13	11 to 76	.071	Toll entrance and long trunks.
16	11 " 152	.071	
19	6 " 455	.090	Trunk and long subscriber lines.
22	11 " 909	.089	Subscriber lines.
24	11 " 1212	.085	Short subscriber lines.

The insulation withstands a potential test of 500 volts (maximum instantaneous value). The increasing number of pairs per cable and

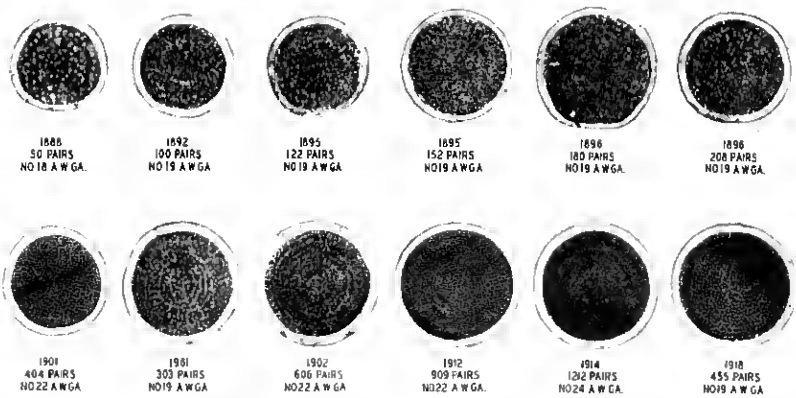

Fig. 5—Principal stages in the development of paper-insulated cable

the corresponding decreasing cost per mile of circuit resulting from the changes described is shown in Figs. 5 and 6.

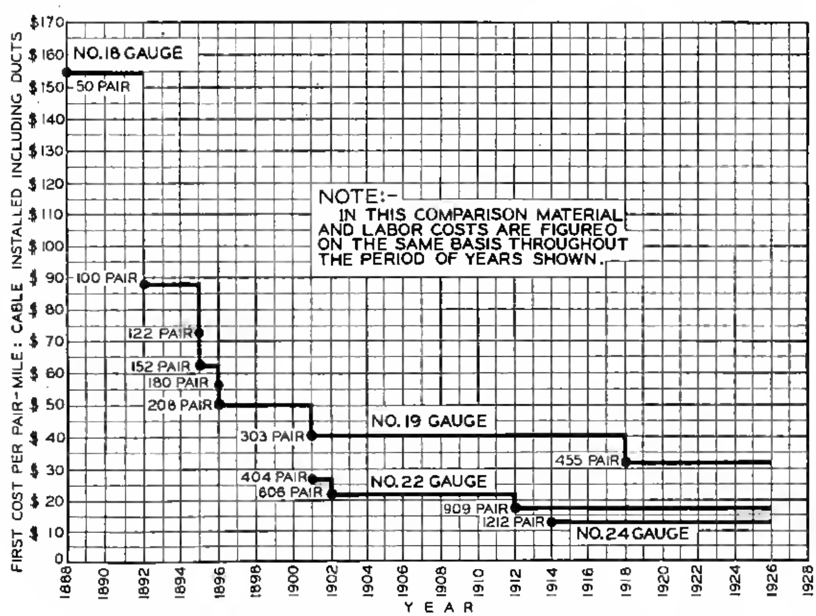

Fig. 6—Cost of a mile of circuit in full-size cable

With the growth of large office buildings and further increases in the demand for telephones in the great cities, even 1,212 pairs of wire per

cable were in some cases found to be inadequate, and in answer to the demand a cable has been developed containing 1,818 pairs of 26 A.W.G. wires within a sheath having an inside diameter of 2⅝ in.

These wires are insulated with paper 7/32 in. wide and 1¾ mils thick by the use of specially designed insulating heads and, instead of being stranded in reverse layers as is the case with older types of cables, they are first stranded in groups of 101 pairs, 18 of these groups being then cabled together to form a compact core.

This method of cabling, called the "unit" type to distinguish it from the layer type, has several advantages, particularly in splicing in the field. Development work on this 1,818-pair cable is not yet complete but there is no reason to doubt that, if there is a demand for a 2,400-pair cable, the demand will be met.

For convenient reference Table 1 has been shown giving the specified limiting characteristics of some of the standard types of non-quadded cables. From the table it will be seen that the larger gauge cables are used mostly for trunk work and the smaller gauges for connections to subscribers. While the electrical characteristics of these non-quadded cables are of prime importance, they do not demand quite the extreme refinement in manufacturing processes required for quadded cables.

The discussion so far has been confined mainly to cable intended for local service, that is, cable providing conductors to connect subscribers directly with the central office and different offices with one another. Gradually, the network of long lines connecting different exchange areas or cities grew and while the early lines were mostly open-wire, it was necessary to provide cable in and near the larger cities to bring these lines into the central offices. Most of the long lines were operated on the phantom principle where four wires are combined to provide two ordinary pair circuits and a third or phantom circuit which uses the four wires simultaneously. It was, therefore, necessary to provide cable for these toll entrances which could also be operated on the same phantom principle. More recently many long toll lines have been placed for their entire length in cables of this type.

One of the greatest difficulties in providing this type of cable was that of building it with sufficiently good electrical balance to avoid serious interference or "crosstalk" between the various circuits in the same four-wire group or "quad," such crosstalk being especially liable to occur because practically all of these lines are loaded. For a given degree of imperfection in capacitance balance, crosstalk is much more serious if the line is loaded than otherwise. A very considerable amount of work was necessary to determine the principles of design and manufacture which have the most influence in bringing about the best balance reasonably attainable.

The specified limiting degree of unbalance of the capacitance in quadded cable is indicated in Table 2, and Fig. 7 is a diagram showing the capacitances involved and a brief explanation of them.

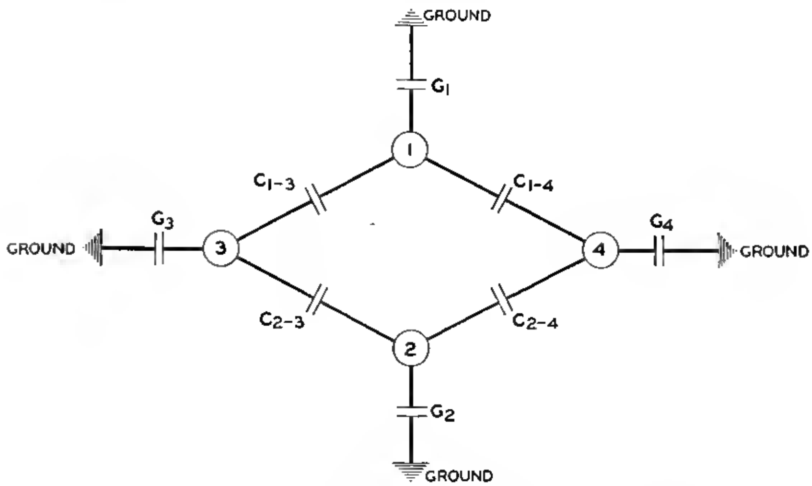

Fig. 7—Diagram showing the capacities involved in capacity unbalances between circuits

TABLE 2

Capacitance in m.f. per mile		Capacitance Unbalance in m.m.f. per 500 ft. length					
Pair	Quad	Side to Side		Phantom to Side		Phantom to Phantom	
Av.	Av.	Av.	Max.	Av.	Max.	Av.	Max.
.068	.112	30	100	120	200	60	600

[1] CLASS I UNBALANCES—PHANTOM TO SIDE

1, 2, 3 and 4 represent the four wires of a quad, of which 1 and 2 form one pair and 3 and 4 form the other pair.

Unbalance between Phantom and Side 1–2 $= 2[C_{1-3}+C_{1-4}-(C_{2-3}+C_{2-4})]+G_1-G_2$
Unbalance between Phantom and Side 3–4 $= 2[C_{1-3}+C_{2-3}-(C_{1-4}+C_{2-4})]+G_3-G_4$

CLASS II UNBALANCES—SIDE TO SIDE

1, 2, 3 and 4 represent the same as in Class I Unbalances.

Unbalance between Side 1–2 and Side 3–4 $= C_{1-4}+C_{2-3}-(C_{1-3}+C_{2-4})$

[1] Capacitance Unbalances involve differences of Direct Capacitances. See G. A. Campbell, *Bell System Technical Journal*, July 1922.

Class III Unbalances—Between Circuits in Different Quads

Unbalances between two phantoms, or between pairs not in same quad, or between a phantom and a pair not in same quad, in each case $=C_{1-4}+C_{2-3}-(C_{1-3}+C_{2-4})$ in which, for

(*a*) *Phantom to Phantom*, 1 represents the two wires connected in parallel to form one pair of a quad, 2 represents the two wires of the quad, and 3 and 4 represent similarly the pairs of another quad.
(*b*) *Pair to Pair*, 1 and 2 represent the two wires of a pair and 3 and 4 the two wires of another pair not in the same quad.
(*c*) *Phantom to Pair*, 1 and 2 represent a phantom as in (*a*) and 3 and 4 a pair as in (*b*).

The type of quad now most commonly used in toll cables in this country is known as the multiple twin type and consists when completed of two twisted pairs which are again twisted around each other. Differently colored wrappings of cotton around the several pairs hold the two wires of the pair together and afford means of identifying various types of quad and pair as used, for example, in the segregation of the circuits operating in different directions in the so-called four-wire circuits.

A type of quad construction different from that described above and commonly known as the "spiral four" type of quad has been used more extensively abroad than here. In this construction four wires are twisted together in such a way that at every position each wire occupies approximately a corner of a square and the two diagonally opposite conductors are used to form a pair.

This construction has the merit of very low mutual capacitance of the pairs, but the disadvantage of very high mutual capacitance of the phantom. It has also been found more difficult with this construction to obtain sufficiently good balance to give satisfactory loaded phantom circuits. This type of quad has, therefore, in some cases been used without utilizing the phantom circuits. The loss of these phantom circuits is less than it might seem at first sight because, on account of the inherently lower pair capacitance for a given space per pair, more wires can be placed in the same space for a given capacitance than with other types of construction.

Another characteristic which under certain conditions is important is the alternating current conductance or leakance. The leakance which is measured in micromhos is that property which determines, under given conditions of potential and frequency, the losses in the insulation. These losses become of greater importance when the cable is loaded than when non-loaded and also of relatively greater importance when the conductors are large because then the dielectric losses become relatively greater in comparison with the lower losses in the decreased resistance of the conductor. For this reason many of the

large gauge loaded toll cables are treated with a special drying process to diminish the leakance.

Under-water Cables

Either quadded or non-quadded cable may be used on occasion for crossing rivers, bays, etc., and in these cases the lead-covered cable is protected by being first served with two or three layers of jute roving impregnated with tar, then wound with galvanized steel armor wire, and again served with jute yarn, impregnated with an asphalt compound, although in many cases at present this outer serving of yarn is omitted. In case of injury causing an opening in the sheath of such a cable, water may enter the interior and interrupt the service. It is also liable to penetrate for a considerable distance and thus ruin a substantial length of cable which it then becomes necessary to replace. To diminish the amount of cable damaged in this way, this type of cable is sometimes made with a very large amount of paper insulation crowded into a small space to make the cable within the lead pipe very dense. The swelling of this paper as it becomes wet tends to retard the penetration of water and to diminish the amount of cable damaged.

This dense core construction has, however, the objection that it tends to produce circuits of lower transmission efficiency on account of the higher capacitance and leakance obtained. For this reason cables for this purpose in many cases are made with less dense core construction similar to that used in land cables but with the core treated so as to provide water barriers at frequent intervals to prevent or greatly diminish the passage of water through the barrier, commonly known as a "plug," so that the damage resulting from an injury to the sheath is substantially confined to the portion between two consecutive plugs.

The Cable Sheath

One of the outstanding developments in cable manufacture which occurred about 1911 was the substitution of 1 per cent antimony in lead cable sheath for 3 per cent tin. The use of tin alloyed with lead for cable sheath had been instituted many years before, as it had been found that such sheath was more durable than sheath composed of lead alone and had better mechanical characteristics.

Exhaustive tests showed that lead-antimony alloy sheath is equal in quality to lead-tin alloy and, although its use required the development of improved methods of mixing and extrusion, it has resulted in large cost savings.

Another decided improvement introduced later was the substitution of vacuum drying ovens for the old gas or steam-heated air ovens.

It was found that the drying time using vacuum ovens was reduced to about one third as compared with hot air ovens, and improved quality and large cost savings resulted.

Before the war the average demand for telephone cable in this country amounted to about two hundred million conductor feet per week. During and after the war this demand steadily increased until now it amounts to about six hundred million conductor feet per week or about thirty billion feet per year, requiring annually forty thousand tons of copper wire, seventy-five thousand tons of lead, and six thousand tons of insulating paper.

Cable-making Machinery

In planning for the manufacture of this quantity of cable, the design of all machinery was reviewed and changes made wherever possible to improve quality or increase output.

A great deal of work was done in improvement of insulating machines, and a ten-head vertical type insulator was developed to replace the older five-head horizontal type for non-quadded light gauge wire. In designing the new machine many improvements were incorporated. The old machines had been built to handle relatively strong paper and heavy wires, and studies indicated that to insulate finer wires successfully with lighter paper, also to run at high speeds without stretching the wire, and to apply a uniform wrapping without backlapping or folding over of the paper and with low breakage per pad the insulators must be rigid, the tension on the wires should be uniform and both supply and take-up mechanisms should operate smoothly.

The relative floor space per head for the ten-head machine including operator's space is about 60 per cent of that taken by the five-head machine but based on production the relative space per unit of production is about 50 per cent. The new machine runs at a head speed of about 3,000 R.P.M., carries a 12-in. pad of paper, and in general is a very substantial machine.

The insulating head, the vital part of the insulating machine, has undergone many changes to accommodate the thinner, narrower insulating papers. One of the most important of these has been to improve the tension mechanism which now consists of a very small multiple disc clutch actuated by a system of levers so that a very light but very uniform tension is applied at all times. This is not only making possible the use of smaller paper ribbon but may permit of changes in the composition of the paper with resultant cost savings. This head is shown in Fig. 8.

Another desirable feature in a paper insulating machine is a bare

wire detector as the insulation sometimes parts after passing through the sizing die or polisher as it is called, separates for a few inches and then picks up and goes on. Many electrical devices have been tried and practically all have the objection of high maintenance cost. A

Fig. 8—Paper insulating head

very simple and effective remedy was the installation of a second polisher placed between the capstan and take-up spool which catches broken paper and pushes it back until the operator sees and repairs it.

The insulating machine used for heavy gauge wire is an eight-head machine built along the same general lines as the ten-head machine. This is illustrated in Fig. 9.

The method of splicing the copper wire is by means of a transformer, the low voltage side of which is equipped with clamps for holding the

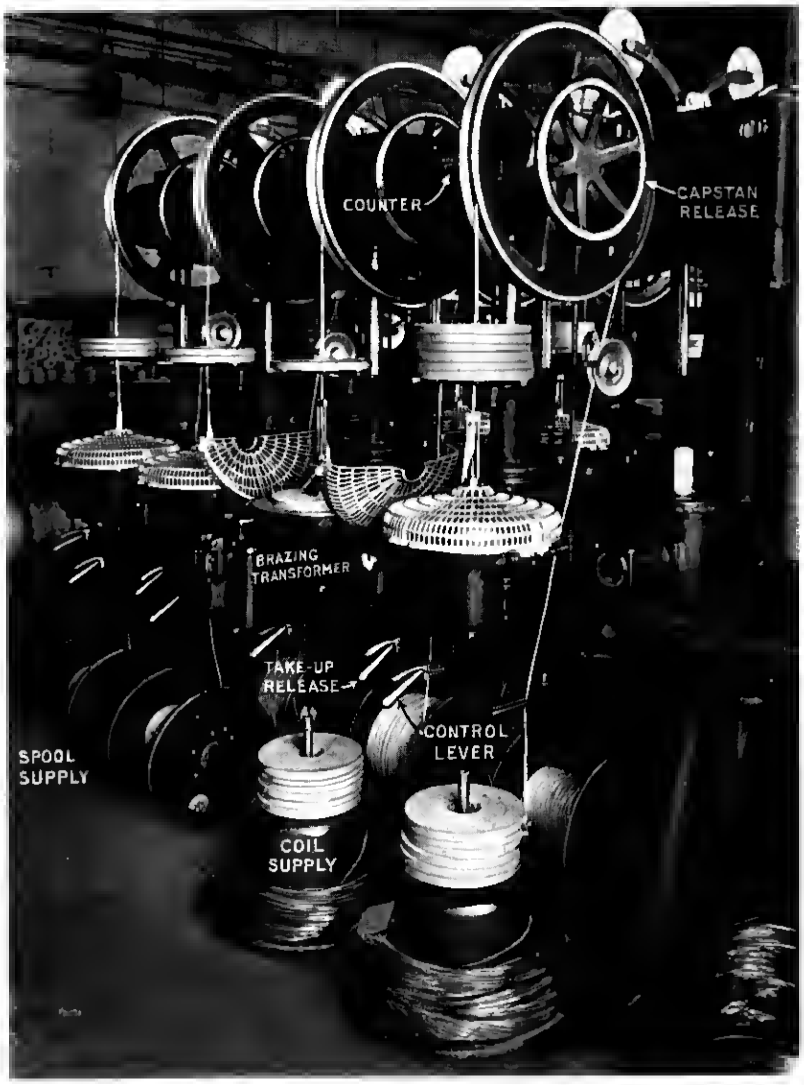

Fig. 9—Heavy wire insulator

two ends of wire which are butted together, heated by electric current and brazed by the application of borax flux and silver alloy solder. The transformer windings are so designed with low internal resistance

that, although different sizes of wire may be handled, the resistance of the wire between the clamps is so large in proportion to the total resistance that it automatically controls the current and prevents overheating of the wire.

Splices in the insulating paper are made by the application of a thin strip of gummed paper.

New twisting machines for non-quadded light gauge wire have been developed and these machines have some unique features which are worth a word of explanation. Fig. 10 shows schematically the old

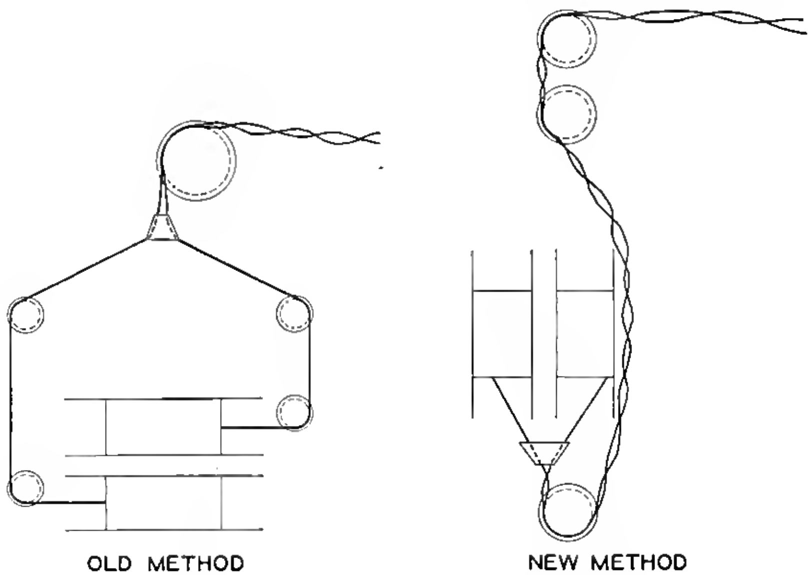

Fig. 10—Schematics of old and new type twisters

type of twister used ten years ago in which the two spools were placed with axes vertical inside of a flier which carried guide bushings through which the wire from the two spools was brought up to the center of the yoke and to the capstan. These machines operated at 500 R.P.M. and produced one twist per revolution. Assuming a 3-in. twist, the output would be about 125 feet per minute. In the new machines the spools are mounted side by side in a flier, the spools not revolving around each other, with axes horizontal, and the wire from each is taken off in a downward direction around a guide pulley and then up through the flier, around another guide pulley and to the capstan. With this arrangement two twists per revolution of the flier are produced and, as the machine is built to operate at 1,000 R.P.M., the out-

put for double the speed of the old machine is four times as great or about 500 feet per minute for a 3-in. twist. Additional features are

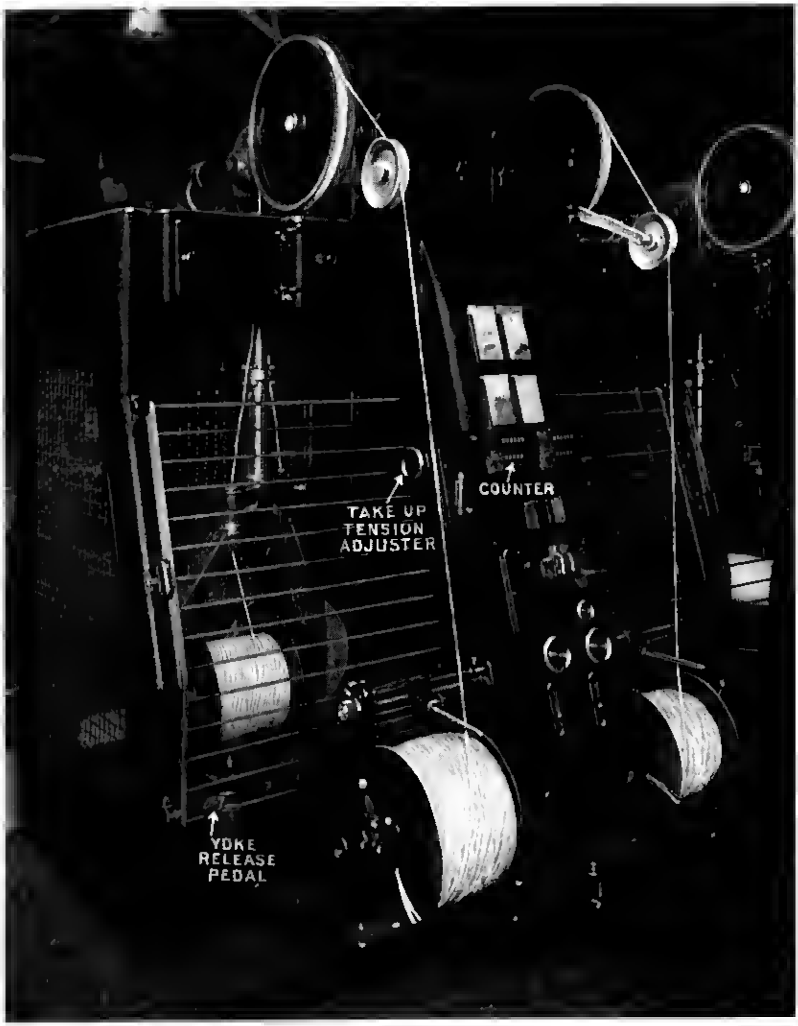

Fig. 11—Combined twisting and quadding machine

special tension devices to insure uniform tension on the wire and supports to assist in loading spools of wire into the yoke.

The twister for pairing and quadding heavy gauge wire in one operation is shown in Fig. 11.

Each spool, containing two conductors, is mounted in a yoke which revolves on its own axis to give the pair twist and the two yokes are revolved around each other to give the quad twist. This is accomplished by an arrangement of change gears from which can be obtained practically any length or direction of twist desired.

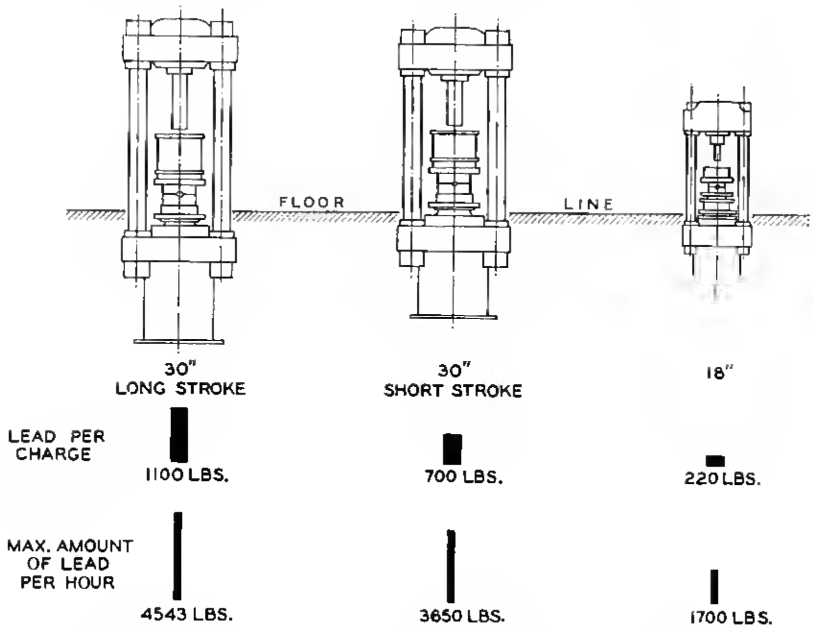

Fig. 12—Schematic showing relative increase in size of lead presses

Modern stranders follow the same general line as the older stranders but the whole design has been reviewed in detail with the view of strengthening and perfecting, and improved tension devices have been developed consisting of a tension arm actuated by the pair which in turn applies a brake to or removes it from the reel head. These are adjusted to give a tension of about three pounds per pair which causes no stretch and prevents over-running. With these, it is possible to run very fine wires at a minimum tension with a maximum smoothness of operation. The drums are gear driven and are capable of running up to 100 R.P.M.

After stranding, the cores are dried under vacuum to remove the moisture from the paper and then are covered with a lead alloy sheath.

It is necessary after the cable is removed from the vacuum drier to keep it in an atmosphere of a low moisture content until the lead sheath is applied. This was formerly accomplished by placing it in an oven

at a temperature of about 160 to 180° F. with a resultant relative humidity of not over 10 per cent. Cables maintained at this humidity would pick up very little moisture but in transit from the vacuum drier to the storage oven some moisture might be absorbed; also working in and out of these hot ovens was not particularly pleasant. Therefore, a method was developed for installing the vacuum driers in such a way that one end opens into an enclosed storage area in which the air is maintained at a temperature of about 100° F. and a relative humidity of less than 10 per cent until the cables are covered with lead. This temperature and humidity are obtained by cooling the incoming air to a dew point corresponding to the temperature and relative humidity desired and then passing it into the oven. A considerable engineering problem was involved in determining the heat given off by the vacuum driers and the hot cables and the additional moisture introduced by infiltration through walls, doors, etc.; also the relation between relative humidity, moisture content of paper and electrical characteristics presented a most interesting field for study.

The method outlined above has proved very satisfactory as the cables do not absorb enough moisture to affect their electrical properties and the conditions in the storage area are not unpleasant; in fact, during the summer time they are somewhat more agreeable than the outside air during periods of high humidity.

The process of applying lead sheath to cable is one which has not undergone any change in principle since sheath was first applied directly to the cable instead of cable being pulled into it. There have been, however, a number of developments tending to improve the quality or increase the output.

In covering a large cable something more than half of the total time of one cycle of operation is taken up by filling the cylinder with lead and cooling under pressure to the point where it can be extruded. The tendency, therefore, has been to build presses with larger lead containers in order to increase the time of extrusion relative to the total cycle.

The diagram (Fig. 12) shows schematically an early type of press, one which was considered standard a few years ago, and one of the presses designed and built recently. Underneath each press is a figure showing the lead content per charge and the relative amount of lead extruded per hour by each of the three presses.

As will have been noted from the diagram, the stroke of the newest type of presses is about one foot longer than that of the former presses although the diameter of the lead container and the diameter of the water ram are the same.

The pressure for operating these presses is furnished by a hydraulic pump, pumping water at six thousand pounds pressure per square

Fig. 13—Electric tractor and trailer for handling cable reels.

inch. Presses were formerly connected to four plunger vertical type pumps, but it was found that more water could be used with the large

Fig. 14—Insulating machines

sizes of cable and, therefore, new pumps were built with six plungers, giving a proportionally greater output. The diameter of the lead ram

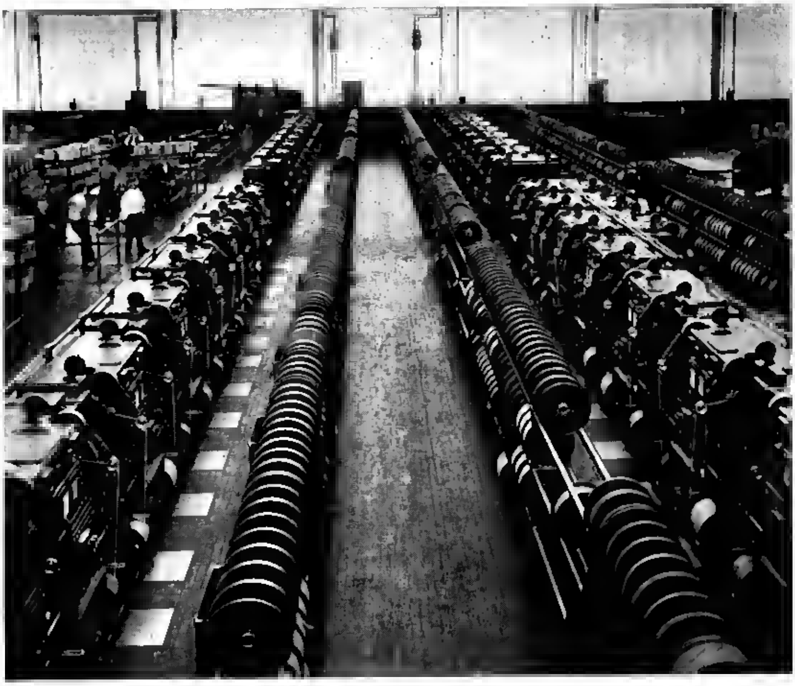

Fig. 15—Twisting machines

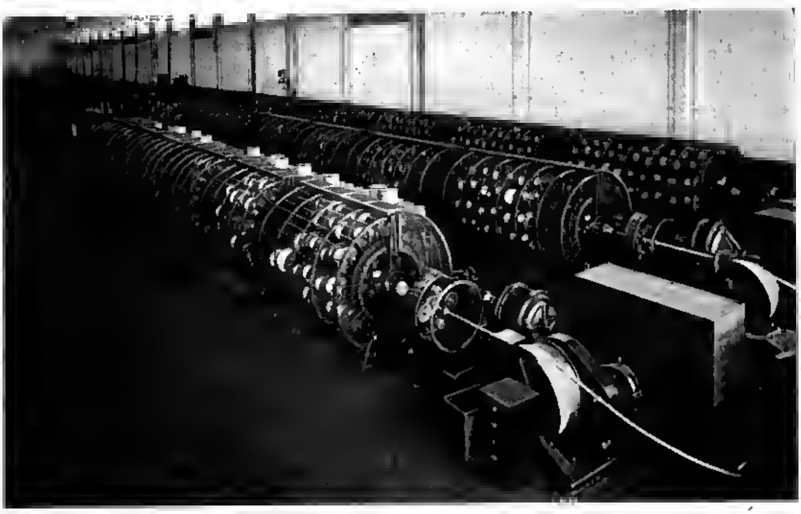

Fig. 16—Stranding machines

Fig. 17—Lead press equipment

Fig. 18—General view of reel yards

is one third that of the water ram, so that the pressure on the lead during extrusion is about 54,000 pounds per square inch.

Aside from increasing output many studies have been made to determine the exact mechanism of lead extrusion, the relative flow of lead in different parts of the extrusion block, the effect of application of heat at different points, etc.

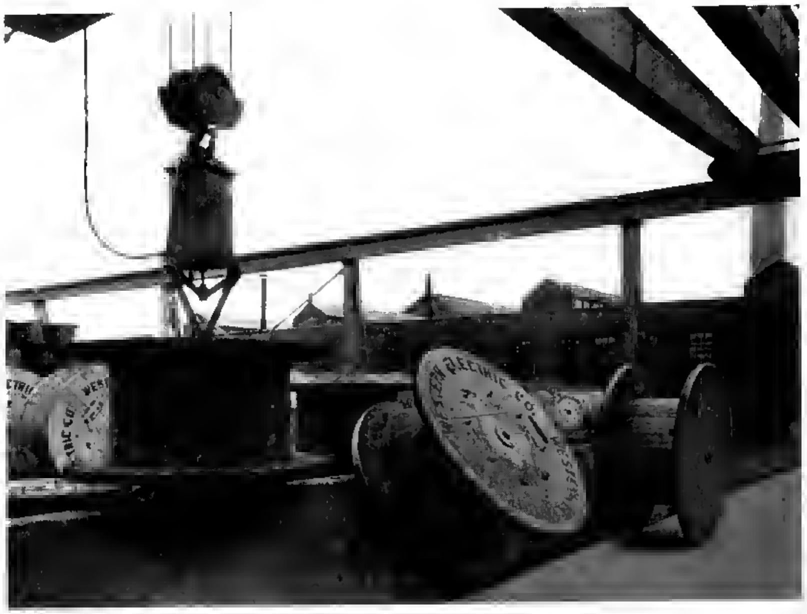

Fig. 19—Delivery of empty reels from yard

An interesting experiment consisted in filling an extrusion block with layers of different colored waxes and noting their flow under pressure. This gave valuable data as to the proper contour of the extrusion chamber.

The concentricity of sheath is affected not only by the contour of the extrusion chamber but also by the manner in which heat is applied; and thickness is affected by temperature and speed of extrusion so that the human element is an important factor, and it is necessary to have thoroughly trained and reliable operators on this kind of work. Temperature indicators are used to show die block temperatures and the temperature of the molten lead is automatically controlled and recorded.

TESTING, STORAGE AND SHIPMENT

Handling of lead-covered cable on reels, the total weight of which runs from one to five tons, is a very distinct problem. This handling from press to test is done by a crane which picks up the reels and carries them to the place where they are to be tested for insulation resistance, capacitance, dielectric strength, etc.

Fig. 20—Crane placing reels on loading platform

After the cables are tested, the ends are sealed and wooden lags are fastened around the periphery of the reels after which the cables are taken to a storage yard until the customer's order is completed, at which time they are shipped. A special tractor and trailer, Fig. 13, has been developed and substituted for manual handling.

Handling cables from the reel yard to the loading platform was a very serious problem, particularly in the winter during snow storms. This was taken care of by the installation of overhead cranes for picking up reels and placing them on the platform.

The lifting mechanism for empty reels consists of a solenoid-operated plunger controlled by the crane operator. The reels are turned on the side, the plunger inserted in the bushing and the operation of the solenoid throws out two lugs which prevent the plunger from being withdrawn and lift the reel. When the reel is to be released, it is put down on an inclined surface which turns it back on to its flanges. This method of lifting empty reels permits them to be stacked one on top of the other and saves storage space.

The lifting mechanism for full reels consists of two side arms with lugs moved horizontally by means of a double-threaded screw and a motor controlled by the crane operator. With this device the crane operator can pick up and put down any reel without the assistance of a ground man.

Figs. 14 to 20 show insulating, twisting and stranding machinery, lead presses and cable reel yard with cranes and special lifting equipment for both empty and full reels.

The methods of cable manufacture are ever changing. What has been described as strictly up to date today will, doubtless, on account of new developments be superseded by new methods, new equipment and new designs, so that the Cable Plant of the future will be different from and more efficient than that of the present.

ERRATA: *Bell System Technical Journal*, April, 1928

Page 327, Table 2—Interchange the number "200" of column 6 and number "600" in column 8.

Page 328, beginning line 4, should read—(*a*) Phantom to phantom; 1 represents the two wires, connected in parallel, of one pair of a quad. 2 represents the two wires in parallel of the other pair of the quad, and 3 and 4 represent similarly the pairs of another quad.

Page 347—Figure 3 should be inverted.